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PHYSICS.—*Determination of thermal conductivity of refractories.*[1]

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Introduction. This paper contains (1) a brief account of thermal conductivity work in progress at the Pittsburgh Experiment Station, U. S. Bureau of Mines; (2) discussion of a suggested formula to correct for transverse heat leakage and departure from a steady state; (3) numerical results up to a maximum temperature of 945°C.

Many investigations of mineral products, especially refractories, require a knowledge of thermal conductivity at high temperatures. Apparatus was designed for this purpose by G. R. Greenslade early in 1922 and later turned over to the present writers for further development. Our first tests above 900°C. were completed in December, 1923, and a report[2] submitted for publication at that time which may be consulted for additional details.

Apparatus. Heat flows outward in both directions from a flat central heater as in the low temperature apparatus of the Bureau of Standards, and it is caused to flow along paths perpendicular to the surfaces of the two samples under test by means of guard-heaters suitably regulated. In order, however, to raise the temperature of the cooler surface of the sample material to within say 100 deg. C. of the temperature of the hotter surface, a requirement peculiar to the high-temperature problem, it is necessary to provide end heaters

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[2] *Conductivity and specific heat of refractories at high temperatures.* By M. D. Hersey and E. W. Butzler. Reports of Investigations, Bureau of Mines, Department of the Interior, Serial No. 2584.

and guard rings, making six heating elements in all. The heat input is measured electrically, and, as a check to detect escape of heat sideways before passing completely through the sample, the original Greenslade design provided very thick iron plates adjacent to the outer surfaces of the two layers of brick under test. If sufficiently accurate measurements of temperature drop through these iron plates can be made, we have a direct measure of the heat outflow, which should agree with the electrical heat input if there is no transverse flow of heat through the bricks.

This check measurement has been omitted by the present writers and the necessary result arrived at in another way as explained below. Other minor modifications were made in completing the construction of the apparatus.

The testing unit thus consists of three flat heaters and guard rings wound with nichrome wire, two layers of brick under test (about two inches thick and one foot square), and four thin metal plates with guard rings (the two plates nearest the central heater being of nickel), beside the two thick iron plates that are not being used. These various layers are cemented together one on top of the other and surrounded on four sides with a very thick layer of silocel bricks. The two end heaters are also, during high temperature tests, protected by a layer of silocel of adjustable thickness.

As finally assembled the apparatus comprises about 18 thermocouple circuits for measuring the various temperature drops, including differential couples for guard ring regulation, and these are connected to a Tinsley vernier potentiometer reading to one microvolt. Three thermo-junctions are installed in each layer of brick under test. Two of these are cemented into grooves close to the respective surfaces for observation of temperature drop during conductivity tests, while the third is an interior junction (half way between the two surfaces) for reference in checking heat flow measurements and in computing the relative specific heat of successive materials from observations on the rate of heating.

The heat input and guard ring control comprises six heavy current circuits connected through water-cooled rheostats to storage battery and alternating current sources.

Observations. After reaching a nearly steady state (which may require over 24 hours) and balancing the guard-heaters so as to insure a flow of heat approximately perpendicular to the surfaces of the brick, the apparatus is ready for final observations. The following

are recorded from time to time: (1) ammeter and voltmeter readings for the central heater, from which to compute $2H$, the total heat input in calories per second; (2) thermocouple readings in microvolts from which to compute three different brick temperatures, viz. the average hot surface temperature t_1, the average temperature at the cooler surface t_2, and the average temperature t_m at the midpoint. In addition the following constants for the apparatus must be known: (1) exact distance between the planes containing the various hot-junctions of the couples by which the brick temperatures t_1, t_2, and t_m are observed; (2) effective area, A, covered by heater wire through which the voltage drop used in computing heat input ($2H$) takes place; (3) calibration data for thermocouples, and other instruments, over the working range.

Computation of conductivity. From the definition of thermal conductivity, k, we have

$$k = \frac{H}{AG} \tag{1}$$

where H is the heat flow (e.g. calories per second) through area A, and G the corresponding temperature gradient. It has been customary to take for G the over-all gradient, which may here be denoted by G_o, i.e.,

$$G_o = \frac{t_1 - t_2}{x} \tag{2}$$

where x is the thickness of the layer of brick comprised between the two isothermal planes t_1 and t_2. But, when G_o is taken for G, it is necessary to use for H the corresponding heat flow H_o averaged from input and outflow observations at the respective surfaces, except in the ideal case when there is no transverse heat leakage at all, and no accumulation of heat within the brick.

On account of the high temperature of the cooler surface of the brick in the present experiments it seemed impracticable to use any flow-calorimeter method for direct measurement of heat outflow, or even to utilize the temperature drop through some low-conductivity material. For these outflow observations would not be of any genuine help unless comparable in accuracy with that of the heat input observations, or, at least, with the accuracy of determination of the thickness factor x.

Considering the above difficulties, our proposed method for applying Eq. (1) has been simply to use for G, not the over-all gradient,

but the actual temperature gradient at the hot surface where H is observed. This can not be directly measured, of course, but it may be computed in terms of the over-all gradient G_o by the relation

$$G = G_o(1 + dG/G_o) \tag{3}$$

where the gradient correction is given by

$$\frac{dG}{G_o} = 4\left(\frac{t - t_m}{t_1 - t_2}\right) \tag{4}$$

As defined already, t_1 denotes the temperature of the junction near the hotter surface of the brick, t_2 near the cooler surface, t represents the mean temperature of the brick $(t_1 + t_2)/2$, and t_m is the observed temperature in the interior of the brick at a distance just midway between t_1 and t_2.

The proof of (4) will readily be apparent by constructing a diagram with ordinates t_1, t_m, and t_2 erected at distances 0, $x/2$, and x from the hot surface, together with a second diagram having ordinates G, $\frac{t_1 - t_m}{x/2}$, and $\frac{t_m - t_2}{x/2}$ erected at distances 0, $x/4$, and $3x/4$ from the hot surface. In effect, G is an extrapolated value derived from two observed gradients, namely those corresponding to the hotter and colder halves of the brick respectively.

Experimental results. The following data from six independent tests on Hytex hydraulic pressed building brick, and on Central of Georgia firebrick (G–3) will indicate the degree of consistency secured by the application of the correction factor in Eq. (4) above. In this table the apparent conductivity values k_a, corresponding to the mean temperatures t, were computed from Eq. (1) by substituting numerical values of G_o where G occurs in the formula, a procedure that would be correct only when there is a steady state and no escape of heat sideways from the brick under test. The true conductivities k corresponding to the temperatures t_1 were computed by reference to Eq. (4).

The values in the last column show a consistent increase of conductivity with rising temperature. Samples have been saved for check determinations in the future by other methods or by other laboratories. In the meantime the apparatus is being futher improved for routine use.

This investigation was undertaken by G. R. Greenslade and F. A. Hartgen on the initiative of John Blizard, formerly Fuels Engineer, Bureau of Mines. It has been continued under the direction of A. C. Fieldner, Superintendent, Pittsburgh Experiment Station, and

in cooperation with G. A. Bole, Superintendent, Ceramics Experiment Station, Bureau of Mines, Columbus, Ohio. The writers are indebted for valuable suggestions or information to Messrs. C. M.

TABLE 1.—THERMAL CONDUCTIVITY RESULTS

BRICK	APPARENT CONDUCTIVITY		GRADIENT CORRECTION	TRUE CONDUCTIVITY	
	t	k_a	$\frac{dG}{G}$	t_1	k
	°C.	c.g.s.	per cent	°C.	c.g.s.
Hytex	140	0.00289	+5.0	155	0.0028
	155	0.00280	−2.8	175	0.0029
	225	0.00280	−4.2	260	0.0029
Georgia	245	0.00219	+13.2	290	0.0019
	370	0.00215	+13.6	450	0.0019
	910	0.00309	+16.0	945	0.0027

Bouton and W. E. Rice of the Bureau of Mines; H. C. Dickinson, C. W. Kanolt, M. S. Van Dusen of the Bureau of Standards; P. Nicholls of the American Society of Heating and Ventilating Engineers; and R. D. Pike of San Francisco.

SPECTROSCOPY.—*Vanadium multiplets and Zeeman Effect.*[1] W. F. MEGGERS, Bureau of Standards.

In a note published last July[2] some regularities in the arc spectrum of vanadium were presented, showing that the multiplets arose from combinations of spectral terms whose maximum multiplicities were even and that the alternation of even and odd structures in arc spectra (alternation law of Kossel and Sommerfeld) was thus verified across the entire table of chemical elements. The vanadium multiplets represented combinations of spectral terms belonging either to quartet or to sextet systems or to intercombinations of these. The spectral lines belonging to each multiplet were selected on the basis

[1] Received February 20, 1924, Published by permission of the Director of the Bureau of Standards of the Department of Commerce.

[2] Meggers, This Journal **13**: 317. 1923.

of constant wave-number differences, temperature classification, and intensity rules accompanying transitions of azimuthal and inner quantum numbers. Some of the same multiplets were found independently by Laporte[3] of the University of Munich.

In an important paper on Term Structure and Zeeman Effect for Multiplets, Landé[4] gives a scheme of the Zeeman patterns for all spectral lines, thus providing another test of the discovered regularities and making it easy to find many more. In the present note, therefore, I am giving a few examples of several types of multiplets in the arc spectrum of vanadium together with the observed and calculated Zeeman effects for the spectral lines. Since the first note was published, the region of the spectrum from violet to red (4500 to 6500 A), in which wave length data of inferior quality existed, has been remeasured on the international scale. Most of the multiplets here discussed are selected from this interval. A table of new wave lengths and other multiplets will be published later in Scientific Papers of the Bureau of Standards.

In the following tables, each of which gives data for one multiplet, the scheme of term combinations is first given and then the observed and calculated Zeeman effects characteristic of the spectral lines are compared. In the arrangement of a multiplet, each spectral line is represented by its wave length in air, above which its arc intensity and temperature class[5] are given while the corresponding vacuum wave number is directly below.

The notation for spectral terms proposed by Landé (loc. cit.) is employed here, since the older notation is inadequate for general use in complex spectra. A spectral term is represented by $n^r_k{}_j$, where n is the total quantum number, k and j are the azimuthal and inner quantum numbers respectively and r is the maximum multiplicity of the system. Values of n are indeterminate until regular series of terms have been established, but the type of any term is fully determined by r, k and j. Quartet and sextet systems are represented respectively by $r = 4$ and $r = 6$; the values $k = 1, 2, 3, 4, 5$, etc., represent what were formerly known as S, P, D, F, G, etc., terms respectively. The j values distinguish the separate levels in poly-fold terms.

[3] Die Naturwissenschaften 11: 779. 1923.
[4] Zeit. f. Physik 15: 189. 1923.
[5] King, Astroph. Journ. 41: 86. 1915.

The Zeeman Effect for Vanadium was published by Babcock[6] for several hundred lines from 3665 A to 6625 A. His observed magnetic separations converted in terms of the separation of a normal triplet as a unit are given in the following tables for direct comparison with the separations calculated from Landé's rules. Parallel components are enclosed in parentheses, followed by the perpendicular components. In some cases, the calculated patterns are rather complex and only one or a few of the stronger components, are expressed in decimal form, the remaining weaker ones being represented by asterisks. Where two or more components are given, the one most intense is distinguished by bold face type. When very close together the magnetic components are often not fully resolved; they appear diffuse or widened. Babcock has indicated some of these cases with the letter w followed by a subscript 1, 2 or 3; w_3 representing the greatest widening observed. The fainter components are seldom observed separately but it is evident that they often influence the determination of the separations for the strong components. With these facts in mind, the agreement between observed and calculated Zeeman effect for vanadium lines must be regarded as fairly satisfactory.

TABLE 1.—VANADIUM MULTIPLET (TYPE PP′ QUARTET)

	n^4_{11}	*144.49*	n^4_{12}	*215.84*	n^4_{13}
	3, IIIA		9, IIA		
n^4_{21}	6565.88		6504.16		
	15226.05		15370.54		
92.42					
	10, IIIA		5, IIIA		10, IIA
n^4_{22}	6605.98		6543.51		6452.35
	15133.63		15278.12		15493.95
187.62					
			7, IIIA		15, II
n^4_{23}			6624.86		6531.44
			15090.49		15306.34

TABLE 1a—ZEEMAN EFFECT

λ	obs.	calc.
6565.88	±(0) 2.61	±(0) 2.67
6543.51	- ——	(0) 1.73
6531.44	(0) 1.57	(0) 1.60
6504.16	(0.52) **1.30**, 2.19	(0.47) **1.26**, 2.20
6605.98	(0.48) 1.34, ——	" " "
6452.35	(0) 1.46	(0.07*) 1.40***
6624.86	(0) 1.36	" "

[6] Astroph. Journ. **34**: 209. 1911.

TABLE 2.—VANADIUM MULTIPLET (TYPE PD QUARTET)

	$n^4{}_{21}$	*72.93*	$n^4{}_{22}$	*26.23*	$n^4{}_{23}$
	7, III		2, IIIA		
$n^4{}_{21}$	4626.48		4610.92		
	21608.67		21681.57		
63.22					
	8, III		8, III		2, —
$n^4{}_{22}$	4640.06		4624.40		4618.80
	21545.42		21618.38		21644.60
102.31					
			15, III		8, III
$n^4{}_{23}$			4646.40		4640.74
			21516.06		21542.30
137.20					
					25, III
$n^4{}_{24}$					4670.48
					21405.10

TABLE 2a.—ZEEMAN EFFECT

λ	obs.		calc.	
4610.92	± (0.90)	——	± (0.81)	0.81, **2.60**
4624.40	(0.85)	$1.44w_2$	(0.26, **0.80**)	0.93, **1.46**, 2.00
4626.48	(1.32)	1.35	(1.33)	1.33
4640.06	(0.76)	0.35	(0.73)	**0.47**, 1.94
4640.74	(0.45)	1.56	(** 0.57)	** 1.48 **
4646.40	(0)	1.00	(0.18*)	0.83 ***
4670.48	(0)	1.18	(0.09**)	1.00 *****

TABLE 3.—VANADIUM MULTIPLET (TYPE PD QUARTET)

	$n^4{}_{21}$	*144.50*	$n^4{}_{22}$	*215.86*	$n^4{}_{23}$
	25,II		5, IIA		
$n^4{}_{21}$	6111.62		6058.11		
	16357.75		16502.23		
63.26					
	15, II		25, I		4, IIA
$n^4{}_{22}$	6135.36		6081.42		6002.60
	16294.47		16439.00		16654.84
102.30					
			40, I		25, I
$n^4{}_{23}$			6119.50		6039.69
			16336.68		16552.57
137.24					
					50, I
$n^4{}_{24}$					6090.18
					16415.33

TABLE 3a.—ZEEMAN EFFECT

λ	obs.	calc.
6002.60	±(0) 2.01	±(0.20*) *** 2.20
6039.69	(0.49) 1.44	(** 0.57) ** 1.48 **
6058.11	(0.85) **0.85**, 2.54	(0.81) 0.81, **2.60**
6081.42	(—, 0.79) 0.89, **1.44**, 1.98	(0.26, **0.80**) 0.93, **1.46**, 2.00
6090.18	(0) 1.22	(0.09**) 1.00 *****
6111.62	(1.28) 1.26	(1.33) 1.33
6119.50	(0.19, 0 55) —, —, —, 1.01	(0.18, 0.54) **0.83**, 1.19, 1.55, 1.91
6135.36	(0.70) **0.50**, 1.86	(0.73) **0.47**, 1.94

TABLE 4.—VANADIUM MULTIPLET (TYPE DD′ QUARTET)

	$n^4{}_{21}$	*66.80*	$n^4{}_{22}$	*103.22*	$n^4{}_{23}$	*127.67*	$n^4{}_{24}$
	8, II		8, II				
$n^4{}_{21}$	5626.01		5604.94				
	17769.65		17836.46				
63.26							
	10, II		10, II		12, I		
$n^4{}_{22}$	5646.11		5624.90		5592.41		
	17706.40		17773.19		17876.44		
102.30							
			12, II		20, I		10, I
$n^4{}_{23}$			5657.45		5624.60		5584.49
			17670.92		17774.11		17901.78
137.23							
					12, II		30, I
$n^4{}_{24}$					5668.37		5627.63
					17636.88		17764.55

TABLE 4a.—ZEEMAN EFFECT

λ	obs.	calc.
5626.01	unaffected	unaffected
5624.90	±(0) 1.16	±(0) 1.20
5624.60	(0) 1.37	(0) 1.38
5627.63	(0) 1.44	(0) 1.43
5604.94	(0.59) **0.58**, 1.83	(0.60) 0.60, **1.80**
5646.11	(0.60) 0.58, **1.79**	" " "
5592.41	(0) 1.52	(0.09*) *** 1.63
5657.45	(0) 1.50	" " "
5584.49	(0) 1.52	(0.03**) ***** 1.57
5668.37	(0) 1.51	" " "

TABLE 5.—VANADIUM MULTIPLET (TYPE DF QUARTET)

	$n^4{}_{42}$	*73.74*	$n^4{}_{43}$	*117.84*	$n^4{}_{44}$	*222.88*	$n^4{}_{45}$
	30, I						
$n^4{}_{31}$	5706.97						
	17517.58						
63.28							
	20, II		40, I				
$n^4{}_{32}$	5727.66		5703.56				
	17454.30		17528.06				
102.26							
	2, IIIA		25, II		60, I		
$n^4{}_{33}$	5761.41		5737.04		5698.51		
	17352.06		17425.77		17543.59		
137.26							
			2, IIIA		18, II		30, I
$n^4{}_{34}$			5782.60		5743.44		5670.83
			17288.48		17406.35		17629.23

TABLE 5a.—ZEEMAN EFFECT

λ	obs.	calc.
5670.83	±(0) 0.66w_2	±(0.05***) 1.00, *******
5698.51	(0) 0.97w_2	(0.07**) 0.90, *****
5703.56	(0) 0.93	(0.09*) 0.77, ***
5706.97	(0) 0.56w_2	(0.20) 0.20, **0.60**
5727.66	(1.10) 0.00, 0.84, 1.56	(0.40, **1.20**) 0.00, **0.80**, 1.60
5737.04	(0.77) 1.23w_2	(** 0.86) ** 1.20 **
5743.44	(0.79) 1.32w_2	(*** 0.67) *** 1.34 ***

TABLE 6.—VANADIUM MULTIPLET (TYPE FF′ QUARTET)

	$n^4{}_{42}$	*122.48*	$n^4{}_{43}$	*142.54*	$n^4{}_{44}$	*166.78*	$n^4{}_{45}$
	30, I		12, I				
$n^4{}_{42}$	4330.03		4307.19				
	23088.04		23210.50				
137.38							
	10, I		30, I		15, I		
$n^4{}_{43}$	4355.96		4332.83		4306.22		
	22950.64		23073.13		23215.70		
186.04							
			10, I		40, I		20, I
$n^4{}_{44}$			4368.05		4341.02		4309.80
			22887.12		23029.63		23196.42
229.60							
					125, II		50, I
$n^4{}_{45}$					4384.73		4352.89
					22800.04		22966.81

TABLE 6a.—ZEEMAN EFFECT

λ	obs.	calc.
4330.03	±(0) 0.40	±(0) 0.40
4332.83	(0) 1.00	(0) 1.02
4341.02	(0) 1.21	(0) 1.24
4352.89	(0) 1.31	(0) 1.33
4307.19	(0) 1.49w_2	(0.31*) *** 1.98
4355.96	(w_2) 1.71	" "
4306.22	(0) 1.49	(0.10**) ***** 1.76
4368.05	(w_1) 1.56	" "
4309.80	(0) 1.47	(0.04***) ******* 1.67
a4384.73	(0) 1.18	" "

(a) This line is an unresolved double and the Zeeman data probably refer to the stronger component which belongs to a different multiplet (Type DF Sextet, (0.08***) 0.90*******).

TABLE 7.—VANADIUM MULTIPLET (TYPE FG QUARTET)

	$n^4{}_{53}$	*122.05*	$n^4{}_{54}$	*157.64*	$n^4{}_{55}$	*192.83*	$n^4{}_{56}$
	40, I						
$n^4{}_{42}$	4577.17						
	21841.44						
137.38							
	15, I		40, I				
$n^4{}_{43}$	4606.15		4580.39				
	21704.06		21826.14				
186.06							
	1, IIIA		25, I		50, I		
$n^4{}_{44}$	4645.97		4619.77		4586.36		
	21518.03		21640.05		21797.68		
229.54							
			2, —		15, I		60, I
$n^4{}_{45}$			4669.30		4635.18		4594.10
			21410.50		21568.14		21760.97

TABLE 7a.—ZEEMAN EFFECT

λ	obs.	calc.
4577.17	±(0) 0.72	±(0.09*) **** 0.83
4580.39	(0) 0.91	(0.02**) 0.87 *****
4586.36	(0) 1.04	(0.03***) 0.98 *******
4594.10	(0) 1.10	(0.03****) 1.00 *********
4606.15	(1.06) —	(**1.14) ** 0.80 **
4619.77	(0) 0.98	(***0.89) *** 1.11 ***
4635.18	(0.61) 1.26D	(**** 0.73) **** 1.25 ****

TABLE 8.—VANADIUM MULTIPLET (TYPE PD SEXTET)

	n^6_{22}	*79.74*	n^6_{23}	*110.73*	n^6_{24}
	15, I				
n^6_{21}	4436.14				
	22535.82				
40.95					
	20, I		15, I		
n^6_{22}	4444.22		4428.52		
	22494.87		22574.59		
66.94					
	15, I		25, I		12, I
n^6_{23}	4457.48		4441.69		4419.94
	22427.91		22507.67		22618.38
91.23					
			30, I		20, I
n^6_{24}			4459.77		4437.84
			22416.43		22527.18
113.43					
					50, I
n^6_{25}					4460.30
					22413.75

TABLE 8a.—ZEEMAN EFFECT

λ	obs.	calc.
4419.94	±(0) 1.73	±(0.03**) ***** 1.86
4428.52	(0) 1.82	(0.01*) *** 1.92
4436.14	(0.51) **1.83**, 2.76	(0.47) **1.94**, 2.88
4437.84	(w_3) 1.60	(***0.44) *** 1.66 ***
4441.69	(0.55) 1.72	(**0.57) ** 1.77 **
4444.22	(0.76) 2.06	(* 0.80) * 2.13 *
4457.48	(w_3) 0.52, 1.17	(0.37 *) **0.54**, 1.28 **
4459.77	(w_2) 0.99	(0.15 **) 0.84 *****
4460.30	(0) 1.22	(0.08 ***) 1.00 *******

TABLE 9.—VANADIUM MULTIPLET (TYPE DD' SEXTET)

	n^6_{21}	*40.40*	n^6_{22}	*68.22*	n^6_{23}	*98.92*	n^6_{24}	*133.50*	n^6_{25}
	a		50, I						
n^6_{21}	4116.61		4109.78						
	24284.99		24325.36						
40.90									
	60, I		4, I A		60, I				
n^6_{22}	4123.56		4116.70		4105.17				
	24244.06		24284.48		24352.70				
66.93									
			60, I		50, I		60, I		
n^6_{23}			4128.08		4116.48		4099.80		
			24217.55		24285.77		24384.60		
91.24									
					60, I		60, I		50, I
n^6_{24}					4132.02		4115.18		4092.69
					24194.45		24293.45		24426.91
113.48									
							60, I		100, I
n^6_{25}							4134.50		4111.79
							24179.93		24313.47

TABLE 9a.—ZEEMAN EFFECT

λ	obs.	calc.
a4116.61	— — — —	±(0) 3.33
b4116.48	±(0) 1.60, 3.29	(0) 1.66
4115.18	(0) 1.53	(0) 1.58
4111.79	(0) 1.46	(0) 1.56
4109.78	(0.71) 1.07, 2.48	(0.73) 1.14, 2 60
4123.56	(0.76) 1.08, 2.52	" " "
4105.17	(0) 1.47	(0.10 *) 1.34 ***
4128.08	(0) 1.47	" "
4099.80	(0) 1.43	(0.04 **) 1.41 *****
4132.02	(0) 1.45	" "
4092.69	(0) 1.40	(0.02 ***) 1.44 *******
4134.50	(0) 1.45	" "

a. Although the line 4116.61 A is not recorded in any published wave length tables, Professor H. N. Russell informs me it is clearly visible in the Mt. Wilson sun-spot spectrum in which the lines of this multiplet are perceptibly strengthened.

b. The component 3.29 probably belongs to 4116.61 A.

TABLE 10.—VANADIUM MULTIPLET (TYPE DD' SEXTET)

	n^6_{31}	*40.40*	n^6_{32}	*71.92*	n^6_{33}	*104.22*	n^6_{34}	*135.80*	n^6_{35}
	8, IIA		15, I						
n^6_{31}	6258.60		6242.80						
	15973.62		16014.04						
40.94									
	15, I		—, —		30, I				
n^6_{32}	6274.67		6258.80		6230.74				
	15932.70		15973.09		16045.04				
67.08									
			20, I		8, IIA		30, I		
n^6_{33}			6285.18		6256.91		6216.37		
			15906.04		15977.92		16082.12		
91.26									
					20, I		30, I		30, I
n^6_{34}					6292.86		6251.83		6199.20
					15886.64		15990.89		16126.65
113.45									
							15, I		30, I
n^6_{35}							6296.52		6243.11
							15877.41		16013.24

TABLE 10a.—ZEEMAN EFFECT

λ	obs.	calc.
6258.60	±(0) 3.22	±(0) 3.33
a6258.80	— —	(0) 1.86
6256.91	(0) 1.61	(0) 1.66
6251.83	(0) 1.54	(0) 1.58
6243.11	(0) 1.56	(0) 1.56
6242.80	(0.76) 1.80	(0.73) 1.14, 2.60
6274.67	(0.62) 1.25, 2.45	" " "
6230.74	(0) 1.40	(0.10 *) 1.34 ***
6285.18	(0) 1.56	" "
6216.37	(0) 1.46	(0.04 **) 1.41 *****
6292.86	(0) 1.50	" "
6199.20	(0) 1.46	(0.02 ***) 1.44 *******
6296.52	(0) 1.51	" "

a. This line is either absent or abnormally weak.

PROCEEDINGS OF THE ACADEMY AND AFFILIATED SOCIETIES

THE GEOLOGICAL SOCIETY

373D MEETING

The 373d meeting was held in the Cosmos Club, October 25, 1922, with President Alden in the chair and 52 persons present.

Program: E. S. LARSEN: *Origin of some corundum-bearing rocks.*

EDWARD SAMPSON: *Ferruginous cherts of Notre Dame Bay, Newfoundland.* This paper was discussed by Messrs. H. S. WASHINGTON, T. W. VAUGHAN, and C. A. MATLEY, Government Geologist of Jamaica, with replies by Mr. Sampson.

E. G. ZIES: *Fumarole minerals of the Katmai region.* This paper was discussed by Messrs. HESS, HEWETT, WELLS, and FOSHAG, with replies by Mr. Zies.

374TH MEETING

The 374th meeting was held in the Cosmos Club, November 8, 1922, with President Alden in the chair and 56 persons present.

Informal communication: David White discussed the Pleistocene cypress swamp in the excavation for the Walker Hotel, Connecticut avenue and L street.

Program: C. A. MATLEY, Government Geologist of Jamaica: *Notes on the Lameta formation of India and its dinosaurian remains.* Dr. Matley's paper was discussed by Messrs. WHITE, VAUGHAN, and REESIDE, with replies by Dr. Matley.

A. C. SPENCER: *The geology of dam sites.* This paper was discussed by Messrs. VAUGHAN, LEE and MISER.

G. F. LOUGHLIN: *The ore deposits of Leadville.*

375TH MEETING

The 375th meeting of the Geological Society was held in the Cosmos Club, November 22, 1922, President Alden presiding and 48 persons present.

Program: G. E. P. SMITH, Irrigation Engineer, University of Arizona: *The effect of transpiration of trees on the ground-water supply.* Prof. Smith's paper was discussed by Messrs. BRYAN and THOMPSON.

AUGUSTUS LOCKE: *Outcrops and ore deposits.* Discussion by A. C. SPENCER AND D. F. HEWETT; questions by H. G. FERGUSON and SIDNEY PAIGE; and replies by Mr. Locke.

376TH MEETING

The 376th meeting was held in the Cosmos Club, December 13, 1922, with Vice-President Stephenson in the chair and 73 persons present. The retiring president, W. C. ALDEN, delivered his Presidential address: *The physiographic development of the northern Great Plains.*

30TH ANNUAL MEETING

The 30th annual meeting was held in the Cosmos Club, December 13, 1922, with President Alden in the chair and 55 members present. The following officers were elected for the ensuing year: *President,* G. F. LOUGHLIN;

Vice-Presidents, L. W. STEPHENSON and W. T. LEE; *Treasurer*, H. D. MISER; *Secretaries*, KIRK BRYAN and C. WYTHE COOKE; *Members-at-large* of the Council, NORMAN L. BOWEN, JOHN D. NORTHROP, OSCAR E. MEINZER, PAUL V. ROUNDY, GEORGE STEIGER; Nominee for Vice-President, Washington Academy of Sciences, WM. C. ALDEN.

377TH MEETING

The 377th meeting was held in the Cosmos Club, January 10, 1923, with President Loughlin presiding and 57 persons present.

Informal communication: Lawrence LaForge discussed the excavation for the Walker Hotel.

Program: A. J. COLLIER: *Some features of the geology of the Little Rocky Mountains.* Discussed by Messrs. MEINZER, HEALD, REEVES, WHITE, VAUGHAN, and SPENCER.

M. R. CAMPBELL: *The Pulaski overthrust fault of southwestern Virginia.* Discussed by Messrs. STOSE, SPENCER, ULRICH, and VAUGHAN.

N. H. DARTON: *Some Arizona problems.* Discussed by Messrs. MISER, LEE, REESIDE, WHITE, SPENCER, and HEALD.

JOINT MEETING

A joint meeting with the Washington Academy of Sciences was held in the Cosmos Club, January 24, 1923, with President T. Wayland Vaughan of the Washington Academy of Sciences in the chair and 87 persons present.

Program: Prof. EMMANUEL DE MARGERIE, Director of the Geological Survey of Alsace-Lorraine: *The structure of the Alps.*

378TH MEETING

The 378th meeting was held in the Cosmos Club, February 14, 1923, with President Loughlin in the chair and 66 persons present.

Informal communications: T. Wayland Vaughan announced the discovery of *Orthophragmina* in the Ocala limestone of Peninsular Florida. D. F. Hewett reported a wider distribution of Jarosite than had heretofore been supposed. Discussed by President Loughlin.

Program: FRANK REEVES: *Geological structure of the Bearpaw Mountains, Montana.*

W. T. THOM, JR.: *Origin of the structural features of Montana and Wyoming.*

These papers were discussed by Messrs. LEE, HEWETT, VAN ORSTRADD, MANSFIELD, WHITE AND LOUGHLIN.

379TH MEETING

The 379th meeting was held in the Cosmos Club, February 28, 1923, with President Loughlin in the chair and 48 persons present.

Program: CHARLES BUTTS: *Geological sections and crustal shortening in central Pennsylvania.* Discussed by Messrs. MANSFIELD, LEE, WHITE, BOWIE, and LA FORGE, with replies by Mr. Butts.

GEORGE W. STOSE and ANNA I. JONAS: *Ordovician overlap in the Piedmont of Pennsylvania and Maryland.* Discussion by Miss BASCOM, and Messrs. BASSLER, KEITH, GOLDMAN, and BUTTS, with replies by the speakers.

380TH MEETING

The 380th meeting was held in the Auditorium of the Department of the Interior, March 14, 1923, in joint session with the Washington Academy of Sciences, the Biological Society of Washington, and the Botanical Society of Washington, President Loughlin presiding and 350 persons present. The program consisted of a symposium on: *The fossil swamp deposit at the Walker Hotel site, Connecticut Ave. and De Sales Street, Washington, D. C.* The papers presented at this meeting have been printed in this JOURNAL (Vol. 14, No. 1).

381ST MEETING

The 381st meeting was held at the Cosmos Club, March 28, 1923, President Loughlin presiding and 49 persons present.

Informal communication: Frank L. Hess: *Quartz glass.*

The regular program was a discussion of the problem of the Tertiary-Quaternary boundary. JOHN C. MERRIAM: *Pliocene and Pleistocene deposits of California.* LAURENCE LAFORGE: *Résumé of the Pliocene-Pleistocene question.*

SPECIAL MEETING

A special meeting of the Geological Society was held jointly with the U. S. Army Air Service in the Auditorium of the Interior Building, April 10, 1923, with General William Mitchell presiding and 200 persons present.

Program: Geology as seen from the air.

Wing Commander M. G. CHRISTIE, of the British Embassy, described his use of the geology of England in aviation. WILLIS T. LEE gave illustrated notes on American geology. Motion pictures of the Grand Canyon and of Vesuvius in eruption were shown.

382D MEETING

The 382d meeting of the Society was held at the Cosmos Club, April 11, 1923, with President Loughlin in the chair and 47 persons present.

Informal communication: CHARLES BUTTS: *Fossil algae in the Ocoee formation.*

Program: KIRK BRYAN: *Pedestal rocks near Lees Ferry, Arizona.*

J. D. SEARS: *Relation of the Browns Park formation and the Bishop conglomerate and their rôle in the origin of Green River.* Discussed by Messrs. LEE, REESIDE, ALDEN, CAPPS, and SAMPSON.

FRANK L. HESS: *Uses of the rarer metals.*

JOINT MEETING

A joint meeting Society with the Washington Academy of Sciences and the Philosophical Society was held in the Auditorium of the Interior Building April 18, 1923, President Vaughan of the ACADEMY presiding and 175 persons present.

Program: The Taylor and Wegener hypotheses on the lateral migration of land masses. FRANK B. TAYLOR: *The lateral migration of land masses.* R. A. DALY: *A critical review of the hypotheses.* W. D. LAMBERT: *The mechanics of the hypotheses.*

383D MEETING

The 383d meeting was held at the Cosmos Club, May 9, 1923, with President Loughlin in the chair and 46 persons present.

Informal communications: Laurence LaForge called attention to an article by R. L. Sherlock in the April, 1923, issue of the Geographical Journal on the influence of man as an agent in geographical change.

Program: WILLIAM BOWIE: *The theory of isostasy and its significance in geology.*

384TH MEETING

The 384th meeting was held at the Cosmos Club, November 14, 1923.

Informal communications: W. C. MENDENHALL exhibited a series of colored panoramas of the Alps, sent by Prof. E. de Margerie to Prof. W. H. Holmes.

Program: M. R. CAMPBELL: *Value of airplane photographs in geologic mapping.* Considerable speculation has been indulged in regarding the value of airplane photographs in geologic mapping. During the past summer the writer had the good fortune to have such photographs of a considerable portion of a coal field he was mapping on the edge of the Great Valley where it is crossed by New River in southwestern Virginia.

The photographs were taken with a Bagley three-lens camera at an altitude of about 12,000 feet, giving a scale of about 3 inches to the mile. Although the scale is small, almost every object in the landscape could be identified, even down to individual trees, and the writer was surprised at the great amount of detail showing on densely brush-covered ridges and in forested regions.

The photographs were given serial numbers in the order in which the flight was made. Each morning the writer selected such prints as covered the territory to be examined during the day, and these were clamped to a large square notebook by a steel desk clamp. Geologic boundaries were sketched directly on the photographs with a soft pencil, but descriptive notes had to be written in the notebook with tie letters or numbers to show their location on the map. Strike lines could not be plotted directly on the photographs, until the photograph was oriented by the determination of the bearing of some straight line, such as a straight stretch of road or some land line.

Great saving of the time and energy of the geologist was effected because, with the photographs in hand, it was rarely necessary to resort to pacing in order to determine location, for the forests and even individual trees, fence lines, and farm crops, together with roads, railroads, streams if large, and most objects of the landscape, were clearly recognizable. Another great saving in time was effected by the aid the photographs gave in finding old roads in wooded areas, in showing at once how one might cross certain territory where there are no public roads, and in enabling one to determine his location in dense brush and even in forested areas.

The writer estimates that in doing geologic mapping by the aid of airplane photographs, in such an area as that mentioned above, fully 50 per cent of the time of the geologist is saved and much greater accuracy of location is obtained than is possible by the use of the best contour map, unless a planetable survey is made when the geologic work was being done.

The cost of aerial photographs has not yet been determined, but it appears not to be prohibitive and, considering the saving that may be effected, it may prove to be cheaper than ordinary mapping. (*Author's abstract.*)

GEORGE S. RICE: *Origin of pockets of high pressure gas in coal mines.* Local concentrations of high pressure gas in crushed coal where the measures have been contorted or compressed by geologic movements constitute a serious menace to life in coal mining in Belgium and British Columbia, where the gas is principally methane; and in small coal basins of central France, where the gas is carbon dioxide. The most disastrous outburst of coal dust and gas occurred in 1879 at the Agrappe Mine, Mons, Belgium, in which the gas reversed the ventilation, smothered 121 men, became ignited at the top of the shafts, and burned four hours. Outbursts of the kind are not known to have occurred in mining operations in the United States, but may occur in future deep mining in the western mountains and in Alaska.

Unsatisfactory hypotheses that have been advanced to explain these outbursts are: (1) accumulation of gas in pores and cavities; (2) Morin's theory of decomposition of coal after relief of pressure; (3) Ruelle's theory first of polymerization of hydrocarbons then of reversion to a gaseous state after relief of pressure. A better explanation is that carbon dioxide gas migrates to the crushed area, becomes trapped, and pressure possibly increased by subsequent earth movements. Hydrocarbon gas may be distilled locally and increase the pressure. Experiments have shown that pulverized coal will adsorb 3 or 4 times its volume of gas under atmospheric pressure; under high pressure a vastly greater volume might be adsorbed. Gas may be held in practically liquid state by the surface tension of minute particles, some almost molecular, which have in the aggregate a vast amount of surface. (*Author's abstract.*)

385TH MEETING

The 385th meeting was held in the Auditorium of the Department of the Interior, November 28, 1923.

Program: D. F. HEWETT: *Dolomitization near Goodsprings, Nevada.* Upper Paleozoic limestones of southern Nevada are widely altered to dolomite. The alteration is shown (1) by the change in color from dark and light gray to cream and white; (2) by a change in texture from very fine grained to medium or coarse grained; and (3) by a change in chemical composition from material containing 94 to 99.5 per cent calcium carbonate to that containing from 90 to 98 per cent dolomite. The process of alteration also involved the elimination of carbonaceous matter, the addition of small amounts of iron and silica, and generally the obliteration of fossil remains. It was accomplished without appreciable change in volume of the rocks.

The altered rock is sharply separable from the original limestone and the surface of contact is commonly either bedding or joint planes, but here and there in homogeneous material is a smoothly irregular surface. Where the limestones are thin-bedded (Devonian and Pennsylvanian) some beds are extensively altered and others nearby are not affected. They are not altered over such large areas as the massive limestones (Lower and Upper Mississippian). One massive bed, about 300 feet thick, is almost completely altered over an area 10 by 20 miles. The overlying thinner beds are altered only over areas that range from a few hundred to 10,000 feet square. Locally,

groups of beds 1500 to 2000 feet thick are completely altered over such areas.

The process of dolomitization appears to be related to the intrusion in early Tertiary time of a group of small sills and dikes of orthoclase porphyry and to the deformation which the rocks underwent during and following their intrusion. The intrusives appeared early in a period of thrust faulting, which was followed by a group of early normal faults. Locally, masses of rock adjacent to these faults are altered to dolomite. No dolomitization is associated with a later system of normal faults. In late Tertiary times small necks of dense latites locally dolomitized the adjacent limestones, or if they intruded dolomite, accomplished a slight hydration and locally formed veins of brucite.

The process of dolomitization is related to and probably culminated in the deposition of bodies of lead and zinc minerals now exploited in the region. It is a type of hydrothermal alteration. (*Author's abstract.*)

W. T. THOM, JR., and C. E. DOBBIN: *Correlation of the Lebo member of the Fort Union with Cannonball member of the Lance.* Recent field work indicates that in the Plains basin of eastern Montana and western Dakota sedimentation continued without important interruption from marine Cretaceous into Wasatch Eocene. The Lance and Fort Union formations are separable into several lithologic units of large areal extent, and of alternating somber and yellow aspect. In Montana, Fox Hills sandstone is overlain in ascending order by the Hell Creek and Tullock members of the Lance; by the Lebo and Tongue River members of the Fort Union; by the Sentinel Butte shale (Fort Union?); and by the Wasatch Ulm coal group. In Dakota, the Hell Creek member (Lance) is overlain by the interfingering Ludlow, and Cannonball marine members of the Lance; by the Tongue River member of the Fort Union; and by the Sentinel Butte shale; the upper part of the Ludlow and Cannonball members being equivalent to the Lebo shale member of the Fort Union of areas farther west.

The faunal, floral, and lithologic evidence all indicates the local continuity of sedimentation from Fox Hills into Wasatch. The Cretaceous-Eocene contact is provisionally placed at the top of the Tongue River member of the Fort Union, although the base of the member, or the top of the Sentinel Butte shale, may eventually be found to be more convenient planes of separation after further work in related areas.

C. E. DOBBIN and J. B. REESIDE, JR.: *The Lance-Fox hills contact in eastern Montana and the Dakotas.* In this paper were presented conclusions regarding the relations between the Fox Hills and Lance formations, conclusions which have a direct bearing upon the solution for this particular region at least, of the "Laramie Problem." It was shown that the reported unconformities between the Fox Hills and Lance are misinterpretations of geologic relations. It was also shown that the Fox Hills of the Dakotas, containing a Marine Upper Cretaceous invertebrate fauna, can be traced directly into the Fox Hills of Montana which locally contains a Fort Union or early Eocene flora. Evidence was presented to show that the Fox Hills and Lance represent continuous deposition, the Fox Hills of Montana being

deposited in marine, brackish, and fresh water contemporaneous with the deposition in a receding sea, of the Marine Fox Hills of the Dakotas while the Lance represents the inauguration of delta and flood plains deposits succeeding the retreat of the Interior Sea to the east. (*Authors' abstract.*)

This paper and the preceding were discussed by Messrs. STANTON, STOSE, THOM, MANSFIELD, and LEE.

386TH MEETING

The 386th meeting was held at the Cosmos Club, December 12, 1923. The presidential address of the retiring president, Dr. GERALD F. LOUGHLIN, *The development and outlook of economic geology*, was delivered. The address will be printed in the Journal of the Washington Academy of Sciences.

The 31st annual meeting was held at the Cosmos Club after the adjournment of the 386th meeting. The following officers were elected for the year 1924: *President:* FRED. E. WRIGHT; *Vice-Presidents:* L. W. STEPHENSON, D. F. HEWETT; *Treasurer:* JOHN B. REESIDE, JR.; *Secretaries:* C. WYTHE COOKE, EDWARD SAMPSON; *Members-at-Large of the Council:* F. C. CALKINS, S. H. CATHCART, W. F. FOSHAG, F. L. HESS, H. E. MERWIN.

C. WYTHE COOKE, *Secretary.*

SCIENTIFIC NOTES AND NEWS

The following meetings of national scientific and technical organizations are scheduled to be held in Washington this spring:

April 18. Association of Makers and Users of Scientific Apparatus.
April 21–26. American Chemical Society.
April 25–26. American Physical Society.
April 28–30. National Academy of Sciences.
May 1–3. American Geophysical Union.

MATTHEW W. STIRLING has resigned as assistant curator, Division of Ethnology, National Museum, to assume new duties in Florida.

HENRY MALLEIS, of the Biological Survey, has returned to the Petén District of Guatemala, where he will endeavor to obtain live specimens of the ocellated turkey for introduction on one of the islands off the coast of Georgia.

ROBERT P. NEVILLE, associate chemist in the Bureau of Standards, died on February 3, 1924, after an illness of several months. Mr. Neville was born September 23, 1894, in Arlington, Kentucky. He was graduated from Baylor University, Waco, Texas, with the degrees of A.B. and A.M. Coming directly from his university work to the Bureau of Standards in 1918, he became a member of the Division of Metallurgy of that Bureau. Mr. Neville's chief scientific work was the preparation and study of the properties of pure iron and several series of its alloys. Recently his attention had been turned in part to investigations of the technic of melting and mechanical working of very pure platinum metals and their alloys.